Final Report

CANMET Contract 03SU 23440-2-9005
Serial #OSU82 - 00106

Synopsis

This report presents the final laboratory test results on the subject program. The only exception is that the long-term strength creep and shrinkage results are not included. The latter will be forwarded as they become available. To date all the ashes appear to give similar results with the exception of the Genisee ash which failed the freeze-thaw test.

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Materials

The reference combined aggregate gradations used for proportions of Sand: 19 mm (1:1.28:0.53) was

Sieve (mm)	% Passing
28	100
20	96
14	80
10	56
5	37
2.25	30
1.25	27
630×10^{-3}	13
315×10^{-3}	2
160×10^{-3}	1

The mix design used throughout was (kg/m^3)

Cement (Type 10)	314
Fly Ash @ 30% by wt. cement replacement	
Water	157
Sand	627
14 mm C.A.	816
19 mm C.A.	345

The air entraining admixture used was Grace's Daravair.

Introduction

The ashes used were those supplied at the start of the project to a comparison study. Due to problems arising from the sand used at the start of the test program it was decided, with the agreement and support of the contracting agency, to re-cast all test mixes after early results indicated that a number of the mixes exhibited unusual water requirements. Unfortunately, there was insufficient ash remaining to repeat all mixes. In addition, it was not possible to obtain a number of samples due to plant shut down and in one case non-co-operation from the supplier.

All tests were conducted according to the relevant CSA or ASTM specification.

Discussion of Test Results

Table 1 indentifies the various fly ashes used in the second program. Identification and details of the other materials used in the program were provided in an earlier report.

Table 2 summarizes the properties of the wet concrete. This table also gives the mix compressive strengths up to 90 days and the mix modulus of elasticity @ 28 days. The most significant feature of these results is the high strength and modulus of FA 4. This mix also had the lowest air content and, as we shall see later, the poorest durability.

In Table 3 the creep results are presented. It is difficult to assess the significance of some of the differences between mixes, principally due to the number of test specimens used. It would appear however that the FA 4 mix, which gave the highest strength and stiffness

@ 28 days exhibits less specific creep at three months than any of the other mixes. This would be expected.

The drying shrinkage results are presented in Table 4. At 90 days all fly ash mixes, with the exception of FA 1, exhibit less shrinkage than the control mix. With FA 1, the results are similar. If is of interest that once again the only apparent anomaly is the FA 4 mix which exhibits only half the shrinkage of the control mix at 90 days.

The freeze-thaw results are presented in Table 5. The only mix that did not perform well was FA 4.

Conclusions and Recommendations

All of the fly ash mixes tested gave similar results with the exception of mix FA 4. This mix had a (low) borderline air content and gave a higher strength and higher modulus of elasticity than any of the other mixes. This mix failed the standard freeze-thaw test, ASTM C666.

It is recommended that mix FA 4 be repeated.

TABLE 1

Fly Ash Identification

Fly Ash No.	Power Plant
FA 1	Wabamum, Alberta
FA 2	Sundance, Alberta
FA 3	Forestburg, Alberta
FA 4	Genisee, Alberta
FA 8	Boundry Dam, Source II (Boiler #6), Saskatchewan
FA 12	Dalhousie, Boiler #8, New Brunswick
FA 13	Trenton, Unit No. 5, Nova Scotia

TABLE 2

Properties of The Fresh and Hardened Concrete

Mix	Batch	Slump (mm)	Air (%)	Compressive Strength (MPa)				Modulus of Elasticicty (GPa)
				3 Day	7 Day	28 Day	90 Day	
Control	1	90	6	19.2	22.0	28.9	33.6	26.0
	2	90	6.4					
FA 1	1	90	6.2	8.8	14.9	25.9	29.9	25.2
	2	90	6.5					
FA 2	1	60	6.0	16.3	18.6	29.7	34.9	25.8
	2	75	5.4					
FA 3	1	35	5.7	15.7	17.8	30.4	36.0	27.4
	2	45	5.8					
FA 4	1	20	4.7	20.4	23.8	36.3	42.4	30.3
	2							
FA 8	1	75	7.0	16.0	19.0	25.8	33.1	23.9
	2	70	6.2					
FA 12	1	100	5.5	15.9	20.1	26.4	34.0	28.1
	2	100	6.2			25.0		
FA 13	1	80	6.25	17.1	19.5	26.3	35.0	26.8
	2	85	6.25			26.1		

TABLE 3

Creep of Concrete in Compression

Time Under Load	Control			FA 1			FA 2			FA 3			FA 4			FA 8			FA 12			FA 13		
	TD	TC	SC	TD	TC	SC	TD	TC	SC	TD	TC	SC	TD	TC	SC	TD	TC	SC	TD	TC	SC	TD	TC	SC
0	260	0	0	300	0	0	280	0	0	290	0	0	250	0	0	230	0	0	270	0	0	240	0	0
6 hr.	330	70	9	380	80	12	330	50	7	350	60	8				270	40	6	330	60	11	260	20	3
1 day	360	100	13	450	150	22	370	90	12	400	110	14	290	40	5	260	30	4	330	60	11	270	30	4
2	370	110	14	480	180	27	410	130	17	380	90	12				300	70	10	370	100	18	290	50	7
3	370	110	14	520	220	32	440	160	21	400	110	14				340	110	16	380	110	20	290	50	7
4	380	120	15	520	220	32	450	170	22	410	120	16	330	80	10	350	120	17	380	110	20	300	60	9
5	390	130	17	540	240	35	450	170	22	420	130	17	340	90	11	370	140	20	400	130	24	330	90	13
6	410	150	19	560	260	38	470	190	25	420	130	17	350	100	13	380	150	22	410	140	26	330	90	13
7	410	150	19	560	260	38	480	200	26	440	150	19	380	130	16	380	150	22	450	180	33	350	110	16
2 wk.	420	160	21	600	300	44	520	240	31	460	170	22	420	170	21	410	180	26	420	150	27	410	170	25
3	450	190	24	640	340	50	540	260	34	490	200	26	420	170	21	420	190	28	480	210	38	430	190	28
4	470	210	27	650	350	52	560	280	36	510	220	29	430	180	23	450	220	32	520	250	46	450	210	31
2 mo.	520	260	33	730	430	63	610	330	43	600	310	40	460	210	26	510	280	41	560	290	53	470	230	34
3	570	310	40	780	480	71	670	390	51	660	370	48	480	230	29	560	330	48	630	360	65	520	280	41
4				800	500	74	680	400	52				510	260	32	570	340	50	620	350	64	500	260	38
5				830	530	78										600	370	54	670	400	73	560	320	47
δ	7.78			6.79			7.73			7.73			8.01			6.89			5.50			6.80		
f'_c	36.6			25.0			30.4			34.7			38.0			27.3			25.0			26.1		
δ/f'_c	0.23			0.27			0.25			0.22			0.21			0.25			0.22			0.26		

TD = Total Deformation, με
TC = Total Creep, με
SC = Specific Creep, με/MPa

δ = Specimen stress, MPa
f'_c = 28 day compressive strength, MPa
δ/f'_c = Stress to strength ratio

TABLE 4

Drying Shrinkage (με) (exp) → expansion

Age (days)	28	32	38	45	59	87
Drying Time (days)	0	4	7	14	28	56
Mix I.D.						
Control	20(exp)	160	200	250	280	390
FA 1	90(exp)	70	120	180	260	400
FA 2	120(exp)	10(exp)	20	120	230	300
FA 3	100(exp)	100	140	200	230	330
FA 4	140(exp)	70(exp)	30(exp)	60	150	200
FA 8	120(exp)	90(exp)	10(exp)	120	250	350
FA 12	150(exp)	50(exp)	40(exp)	40	140	250
FA 13	100(exp)	20	50	140	210	320

TABLE 5

Results of Freeze Thaw Durability Testing

Mix	Durability Factor (%)	Δ weight (%)
Control	100	-2.3
FA 1	100	-9.0
FA 2	94	-4.9
FA 3	95	-2.9
FA 4	10	-0.5
FA 8	100	-2.4
FA 12	100	-2.6
FA 13	100	-2.3